APPLICATION OF THE TIME-STAGED STRATEGIC APPROACH TO SYSTEM PLANNING

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This paper is concerned with an application of a time-staging approach to transport system planning when there are large uncertainties regarding demand and community acceptance of highway projects. A general strategic conditional approach is presented as one technique for handling the uncertainties associated with any long-range resource allocation problem. An example of the approach applied to a highway planning problem in Santa Barbara, California, is presented, and conclusions are drawn as to its general applicability to other transport planning problems, most notably when network constraints and regional budget constraints provide additional incentives to stage alternatives in a conditional way.

•THERE are three major factors that any planning process designed to be sensitive to community values and environmental concerns must recognize. First, change is endemic in the society in which we live. Community goals and planning objectives, transportation needs, and the impact of transportation facilities on the environment all change over time and require new responses in the planning of transportation systems.

In most states, these changes have been reflected in increasing and more vocal opposition to urban highways, growing pressure to develop mode options other than the private automobile by opening the highway trust funds (both national and state), and a renewed debate over the states' development goals and transportation requirements. The controversies generated by development plans for Mineral King Canyon near Los Angeles and the Boston transportation plan are illustrative of increasing public and private interest in the environment.

The second important factor that must be recognized is that public policy and investment decisions can strongly influence the patterns of change in a region. Though the long-run interaction between the transportation system and the myriad social and economic forces is not well understood, there is much evidence to suggest that the transportation system can encourage growth and development patterns that in turn may place new requirements for capacity on that system. Hence the need for transportation cannot be described in the abstract without consideration of the system proposed to meet that need.

Finally it must be recognized that changes in values, demand for service, and the influence of transportation improvements on these changes cannot be predicted with certainty. In addition to uncertainty in demand and factors influencing demand (e.g., population growth), the resources to be available in the future to meet these demands are also subject to change.

In California, the freeway and expressway system master plan will probably never be implemented in its entirety and certainly not on schedule. Had this been known or anticipated at the time of its conception, there may have been an intermediate system (in scale or location) that could have better served the state's transportation requirements in the 1970s and still provided adequate service in future years. For example, instead of building some major freeways in rural portions of the state, more moderate upgrading might have occurred over a larger segment of the highway system. There

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is currently some discussion within the California Division of Highways of the need to explore more thoroughly the opportunities for constructing interim improvements.

Thus transportation options must be developed with the knowledge that present decisions must be based on an imperfect understanding of the future of the region. Unforeseen changes may require new responses and adaptations that are impossible to fully evaluate at the present time.

Many of the problems currently facing state highway departments are directly related to the inability of the present system planning process to explicitly deal with uncertainty and effectively relate near-term programming decisions to longer range system plans. System planning must focus not only on desirable master plans but on implementation strategies as well.

DEVELOPING STAGING STRATEGIES

Historically, transportation studies have developed a number of candidate systems for some future target year and then chosen one of these plans to be implemented over the time horizon considered. The urban transportation studies done as a result of the 1962 Federal Highway Act focused almost exclusively on evaluating systems to be implemented by some target year. Usually, if alternative networks were even evaluated, there were only minor differences among them (4).

However, transportation plans are not implemented instantaneously in "one shot" but rather as a series of stages over time, and transportation planners ought to examine different strategies for implementing a plan. For example, the 20-year master plan might be divided into 5-year stages with alternative strategies consisting of different actions staged over this time period. Each stage of a particular strategy might include construction of a number of highway links or transit options as well as different studies. At the end of the first stage, the subsequent stages in a strategy could be revised or updated in light of new information or changes that have occurred.

A brief example will illustrate the concept of a time-staging strategy. The approach follows the general sequential decision model described in an earlier work by one of the authors (1). In Figure 1, A_1, B_1, and C_1 represent the potential first-period actions, and L_1 represents an uncertain variable (demand, community acceptance, etc.) that, at the end of the first stage, may affect the feasibility or desirability of particular actions. Associated with each value of L_1 is a probability $Pi(L_1)$. Second-stage decisions depend on both the first-period action and information gained on the L_1 during the first stage.

A staging strategy then represents a first-stage decision leading to a range of choices in later stages. Decisions in future stages are conditional on the impacts of previous decisions and the information gained in the interim. Although each first-stage decision leads to a range of choices available in the succeeding stages, as decisions are made, the number of choices and systems that can evolve during the specified period decreases because of budgetary and time constraints.

In most cases the agency has the option not only of immediate actions—particular transportation system changes—but also of deferring implementation of an action to acquire more information about the problem. For example, if there is a great deal of uncertainty about demand, it might be more efficient in the long run to delay construction of a new system for a period to collect sufficient information to reduce this uncertainty.

The time-staging approach recognizes that significant decisions on a system plan are in reality going to be postponed until environmental impact, corridor, and initial route studies are under way or complete. The mode, scale, specific alignment, and indeed existence of a particular facility may be determined in later phases of planning. Time-staged system plans recognize the possibility of a number of outcomes from these later studies.

By the time-staging actions on facility improvements, emphasis is placed on what choices are available over the planning time horizon and how present decisions affect the range of choices available in future stages. The different sequences can explicitly recognize uncertainty by evaluating the impacts of a number of outcomes from negotiations or impact studies. Thus, staging strategies provide a convenient framework for relating system and project planning by focusing on both short-term decisions and longer range plans.

With the staging approach, initially, no particular "end state" need be identified as a target system. By prematurely focusing on one future system, the master planning approach loses flexibility to revise plans in the future. In addition, by not considering implementation strategies, a master plan often represents an unrealistic goal that may distort near-term project decisions.

LEVELS OF STAGING STRATEGIES

In general, there will be a number of uncertainties present and a wide range of different sequences of actions possible over the planning horizon. Also, probabilities may be different at different stages, and a network simulation model may be required to evaluate alternatives at each stage. Thus, an agency could never expect to provide for all the possible contingencies in developing staging strategies.

Although the resources available for planning will restrict the number of sequences and uncertainties that can be considered, attention need not be limited to one sequence over time. Staging strategies cannot represent a statement of everything that may occur in the future but can represent what appears today to be the major choices facing the decision-making process. Research has been ongoing to develop practical techniques for treating transportation planning as a sequential decision process in the face of uncertainty (1).

To simplify the use of the staging approach, one can define different levels of strategies, each addressing different though related issues. Relating the staging approach to statewide transportation planning suggests the following three levels at which staging strategies for transportation facilities might be developed:

1. Project level—In this case, strategies would trace out alternative ways to improve transportation service in a specific location or alignment over time. The basic choice would be on the scale and timing of improvements. For example, the choices might be to build two lanes now and two later, four lanes now or four lanes later (6). Staging construction would allow expansion if future demand levels are high or delaying expansion if demand is low or improvements in other locations are more urgent.
2. Corridor level—A corridor will be defined as a subarea of the region in which project stagings cannot be considered separately because of network interdependencies. Corridor strategies might consider a number of projects that differ in location and mode as well as scale and timing.
3. Regional level—At this level, a staging strategy would trace out how resources might be shifted among all the investments proposed in the region. The essential trade-off at this level will be the allocation of funds to different corridors or projects based on the possible outcomes of studies and decisions made for staging strategies at these other levels. For example, given high demand in all corridors being studied in the region, large improvements could be funded in some areas with no improvement in others, or intermediate improvements might be funded in all corridors.

Thus a corridor strategy may include a number of project strategies, and, within a region, several independent corridor and project strategies may be developed. When particular projects or corridors are funded for study, any of a number of improvement sequences could develop because a staging strategy represents alternative decisions that may occur over time. At the regional level, all strategies will be related by the budget constraint on transportation improvements.

Figure 2 shows the relation between corridor and regional strategies. In each corridor, A and B, different strategies for improving transportation service could be studied separately. The alternatives implemented in one corridor will not affect the desirability of alternatives in the other, except in terms of restricting the resources available for improvements there. At the regional level, staging strategies trace out the combinations of improvements that can be funded over time in both corridors.

Figure 1. Staging strategy.

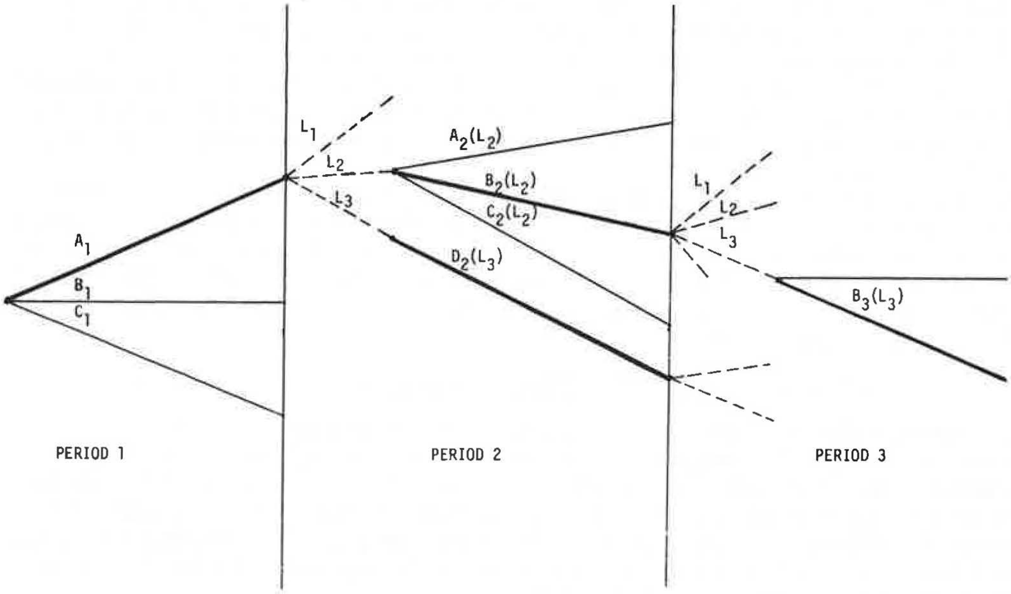
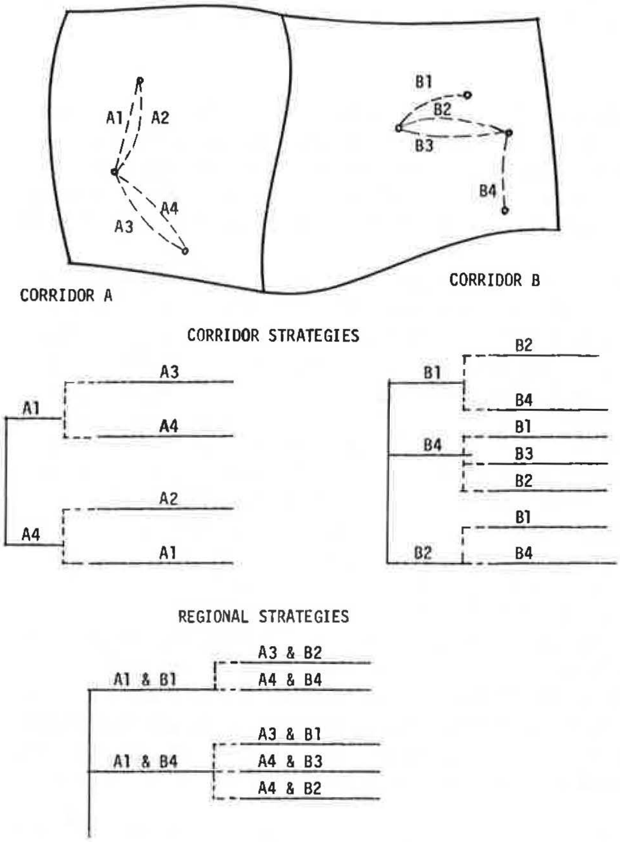


Figure 2. Regional staging strategy.



By considering a range of possible outcomes from the studies in each corridor, regional strategies recognize the budget dependencies between strategies in each corridor without initially restricting the range of solutions studied in either. If only small improvements are acceptable to the communities in B, then more major improvements could be funded in A. Likewise, if communities in both corridors wanted major improvements, then a compromise would have to be achieved with either intermediate improvements funded in both areas or all but minor improvements delayed in one of the corridors.

Because a regional level staging strategy must include decisions on both program selection (set of projects) and individual project development, it must explicitly address the interaction between system and project planning. That is, strategies must recognize that information acquired during more detailed route studies may affect both the schedule and the design of the improvements in that location and in turn affect the scale and timing of improvements in other locations.

APPLICATION OF THE STRATEGIC APPROACH IN CALIFORNIA

To illustrate the concepts involved in a time-staged strategic decision-making process, we developed a case study based on projects currently under way in the California Division of Highways Planning Program. The focal point for the example is the Crosstown Freeway project in the city of Santa Barbara located in District 5 in the state of California. Experience with the Crosstown project highlights many of the limitations of the present process for developing an investment program that the staging concepts can help to address more directly.

The case study makes use of decision analysis in evaluating the expected economic efficiency of different strategies for the Santa Barbara area. The examples demonstrate both the effect of considering the uncertainty of community acceptance of a proposal and the interdependence of projects caused by a budget constraint.

Project Background

The Crosstown Freeway project in Santa Barbara has been concerned with improving the transportation service into and through the city. In particular, the proposed Crosstown Freeway will upgrade the existing four-lane downtown section of US-101 to freeway standards. Currently the downtown section has four signalized intersections and is one of the few remaining segments of US-101 that is not at freeway or expressway standards.

Santa Barbara, a scenic coastal city, has traditionally placed a high value on aesthetics. The existing alignment of US-101 forms a border between the beach and recreational area and the main business district. Figure 3 shows a map of the area and the location of alternatives for the Crosstown Freeway and for two of the proposed bypass routes. During the past 17 years, the controversy surrounding the Crosstown project has been focused principally on the location and design of the freeway. Although many different interest groups within the city have felt some improvements are desirable, a number of nonfreeway alternatives have been proposed, and recently a group of citizens opposing any further improvements on the downtown highway system has emerged. Over the years the city council has steadfastly refused to accept a facility design felt to be detrimental to the city's visual and recreational assets. What began in 1954 as a 1-mile project with cost estimates around $10 million is currently a 2.7-mile project with cost estimates ranging from $38 million to $55 million.

For the most part, the city has favored either a completely depressed freeway or a partially depressed, landscaped alternative. At first, the Division opposed all depressed alternatives because of their high cost and proposed a viaduct design and a number of at-grade alternatives. Subsequently, a groundwater study concluded that a depressed freeway on the existing alignment was unacceptable based on environmental grounds. As each impasse was reached, new alternatives were studied and compromises sought.

As a result of the difficulty with developing an acceptable improvement for the Santa Barbara corridor, the District 5 planning program has experienced a large amount

Figure 3. Santa Barbara corridor.

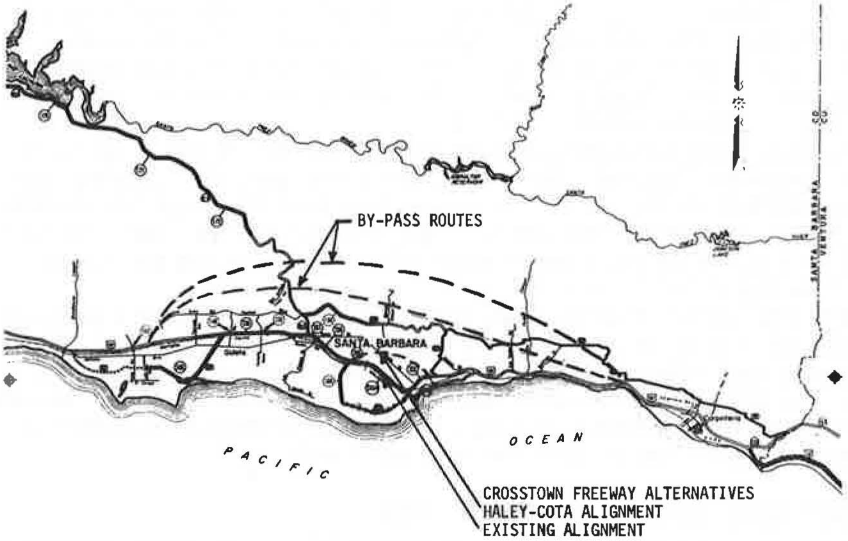
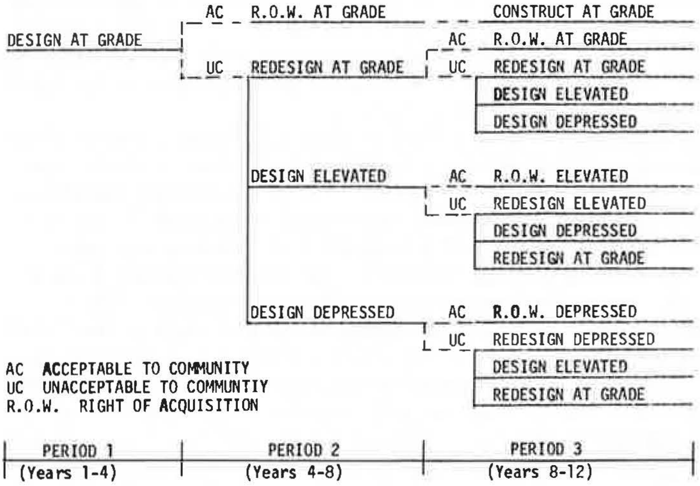


Figure 4. Staging strategy based on designing at-grade alternative in the first period.



of project schedule slippage and reordering of project priorities. Such fluctuations in planning program schedules have made it difficult for District 5 to effectively allocate its resources because the Crosstown project represents a large part of the southern half of District 5's total allocated budget. When the project was continually postponed, augmentation projects had to be found so that legislatively defined District 5 and Santa Barbara County budget minimums could both be met.

Over the years, it has become more and more difficult to find interim projects to substitute for the Crosstown Freeway. Some of these interim projects, advanced for early right-of-way acquisition and construction, have also run into delays and controversy during the necessary negotiations with the communities involved. More importantly, many of the substitute projects are of relatively low priority and are funded primarily to meet the legislated minimums.

One additional problem at the district level is that effective allocation of manpower resources has suffered as a result of delays to the Crosstown Freeway project. When a project is pushed ahead and scheduled for early right-of-way acquisition, personnel must be shifted to this new project and work hurriedly to meet a new deadline. Because District 5 is a relatively small district, it does not have a great deal of flexibility in reassigning personnel and moving projects ahead on short notice.

Project Level Alternatives in the Santa Barbara Corridor

The three freeway designs chosen to demonstrate the time-staged strategic approach at the project level were the depressed alternative on the Haley-Cota alignment, an elevated landscaped fill alternative on the existing alignment, and the at-grade alternative combined with relocating the Southern Pacific tracks along the existing US-101 alignment (Fig. 3).

The decision to be considered in developing staging strategies is which alternative should be advanced to final design in order to present a request for a freeway agreement to the city. Given the size of the District's staff, there are only enough manpower resources to do final design on one of the three alternatives, and therefore a decision must be made to do a final design on one of the alternatives.

The probability of obtaining an agreement on a final design will depend on the alternative chosen. Figure 4 shows one staging strategy based on the decision to do final design on the at-grade alternative. By the second period, if the community accepted the design and signed a freeway agreement, right-of-way acquisition could begin with construction taking place in the third period. If the proposed alternative was unacceptable to the community in the second period, however, the Division would have to redesign the at-grade alternative or do final design on another alternative. Then, depending again on whether or not the community accepted the new design in the third period, right-of-way acquisition could begin or a new design would again be needed.

Thus, assuming that these three freeway alternatives are available, the Division would continue to choose to redesign rather than drop all studies if no freeway agreement was obtained. Figure 4 shows the choices available over a span of three planning periods for one possible alternative. A similar staging strategy can be developed involving a first-period decision to design the depressed or elevated alternatives.

Once a first-period decision is made and the design proceeds, future decisions become conditional on both the previous decision to design a particular alternative and whether or not the design presented to the community was acceptable. A staging strategy then is represented by a first-period decision and a series of conditional future decisions that represent the choices left open over the current planning horizon. The desirability of a particular first-period decision would depend, to some extent, on the choices left open and the magnitude of the uncertainties present.

To simplify the example our attention is limited to the effect of uncertainty on the relative economic efficiency of the three designs, and a straightforward expected value decision analysis is performed. The method assumes that subjective probability estimates are appropriate for explicitly considering uncertainty. [Raiffa (7) discusses in detail decision analysis and the assumptions it makes.]

The cost figures for right-of-way and construction for this example were taken from the final environmental impact statement for this project. The economic efficiency benefits were calculated from the state's planning, programming, budgeting system (PPBS) indexes reported for the project in the 1972 planning program. The benefits for all three designs were assumed identical because each project is assumed to provide the same improvement in service.

The net present value of each alternative strategy is the evaluation technique used, which measures the net economic efficiency benefits of an alternative, given that implementation begins at some specified time. In describing the staging strategies based on doing final design on one of the alternatives during the first 4 years, however, explicit recognition was given to the fact that Santa Barbara may reject any or all of the proposals, and therefore the implementation time of each alternative was uncertain. To account for uncertainty, then, the economic value of an alternative must be weighted by the probability of obtaining community acceptance for that design for any particular period. By using expected values, we assume that the Division is not "risk adverse" (7).

Given the staging strategy shown in Figure 4, the Division can estimate the probability that the design of the at-grade freeway would be acceptable or unacceptable to the community at the beginning of the second 4-year period. Likewise, if the at-grade was unacceptable, one could estimate the probability that designs on any of the three alternatives could be acceptable at the start of the third 4-year period. Once the probability estimates are made, an expected net present value can be calculated for a staging strategy.

To calculate the expected value of a staging strategy, one must use the standard "average-out and folding-back" procedures. This involves working backward through the decision tree, calculating the expected value at each decision point (assuming you have reached this point in the tree), and discounting back until an expected net present value is obtained for each possible first-period decision. This backward search procedure is necessary because the actions in the last period cannot be evaluated until the history of actions and uncertain events up to that period is known.

Thus, one assumes a history of actions and events leading up to the last period and then calculates the expected value over all possible outcomes for each action at that time. The best decision for this point in time is then chosen as that action yielding the highest expected value. For example, we could assume that the at-grade freeway was designed and unacceptable to the communities in the first two periods. In the last period then final design could be done on any of the three alternatives, and an expected value for each could then be calculated.

Using the benefits and costs described previously, and the staging strategies developed as a result of doing final design on one of the three alternatives in the first period, we calculated the expected value of each strategy for a range of probability estimates. One example is shown in Figure 5. Here the probability of the community accepting the depressed alternative was assumed to be 100 percent and for the elevated and at-grade alternatives, 20 percent and 30 percent respectively.

The values shown at the end of the third period were obtained by assuming that, if the community remained opposed to the alternative presented, after the third period no further studies would take place. The $2.86 million net benefit shown for the decision to redesign the at-grade in the third period, then, represents the 30 percent probability of the community accepting the design times the net present value at the time of right-of-way acquisition ($14.3 million) plus the 70 percent probability of no acceptance with a return of zero (because studies are assumed to be dropped).

For the probabilities assumed in the figure, the strategy with the highest expected economic return is to design the at-grade alternative, the second branch of the tree (Fig. 5). If the community rejects the proposal in the second period, the strategy involves redesigning the at-grade facility and, if rejected again, designing the depressed in the third period. In reality, of course, the range of decisions in later stages, as well as the probability estimates, may also change.

The strategies shown were tested with a variety of different probability estimates each time but always assuming less than a 50 percent probability of acceptance for the at-grade and the elevated alternatives and more than a 50 percent probability of acceptance for the depressed alternative. In all cases, the decision to design the at-grade alternative in the first period had the highest expected net present value, whereas the second- and third-period decisions changed as the probabilities shifted.

Naturally, the expected net economic efficiency benefit is not the only criterion to be considered, just as the present PPBS indexes are not the sole consideration in placing projects in the planning program now. Accounting for uncertainty with respect to a quantitative criterion can be accomplished in the formal manner shown for economic efficiency. However, it is only illustrative of how considering uncertainty may affect decisions. In this case, the preservation of the visual connection between beach and downtown provided by the depressed alternative had to be weighed against its greater impact on the relocation of homes and business establishments.

Relating Santa Barbara Corridor Decisions to the Rest of District

Two types of relations may exist among different improvements considered in a planning program. First, within a given area there may be network effects (i.e., changes in traffic patterns of volume) that create dependencies among the scale and timing of proposed improvements. In the case of the Santa Barbara corridor, a number of improvements on US-101 outside the Crosstown section are contingent on a freeway being built. Unless the Crosstown Freeway is constructed, these improvements will also not be constructed.

The second and more general type of relation among improvements is that resulting from the budget constraint. With scarce resources, a decision on a particular improvement must be made in light of the alternative uses available for those resources. Thus, a decision to construct a freeway in Santa Barbara restricts a large amount of funds and manpower from being used elsewhere. We will not illustrate how the desirability of improvements in the Santa Barbara corridor may be affected by improvements being considered elsewhere in the district.

In California, the relation among projects due to the budget constraint has two dimensions because of the existence of budget minimums as well as maximums. In past years in District 5 when the Crosstown Freeway was delayed, substitution projects were needed to meet the District 5 and county minimums. The effect of the minimums was to constrain the geographic area in which substitution projects could be developed.

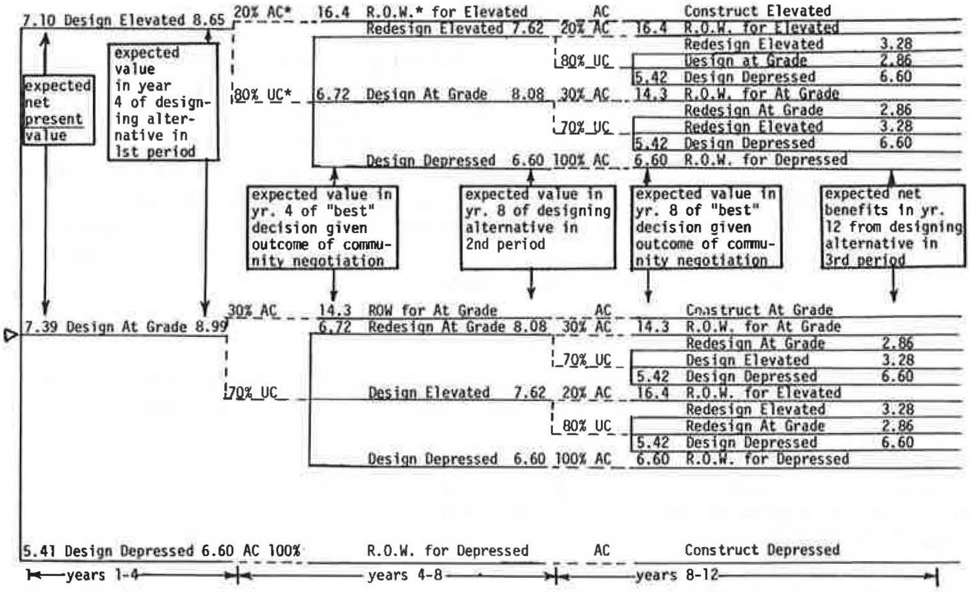
Before adverse environmental impact of a depressed alternative on the existing alignment was uncovered by a groundwater study, the Division had ruled it out as too costly. Before making such an assessment, however, one must consider both the uncertainty associated with the community accepting a particular design and the alternative uses for the funds if the Santa Barbara project is delayed.

The previous example will be modified by assuming that, now if the Crosstown Freeway is delayed, some funds would have to be spent on one or more substitution projects just to meet the district minimum. Furthermore, as before, the only improvement alternatives in the Santa Barbara corridor are the three designs considered earlier.

Given these conditions, two substitution programs were developed from projects identified in the 1972 Multi-year Financial Plan as candidate substitution projects if the Crosstown is delayed. The net present value of these substitution programs was negative, confirming the Division's judgment that many of the substitution projects were low-priority improvements whose schedules had been pushed forward prematurely just to meet the District 5 and county minimums.

Figure 6 shows how the decision to design a freeway alternative in the Santa Barbara corridor is related to the overall District 5 planning program. The decision to design a particular freeway alternative can again result in two outcomes. If the community accepts the design, right-of-way acquisition can begin in the second period, followed by construction in the third. If the design is unacceptable, a substitution program must be funded in the second period and a decision made to redesign the alternative rejected or design one of the other two freeway options.

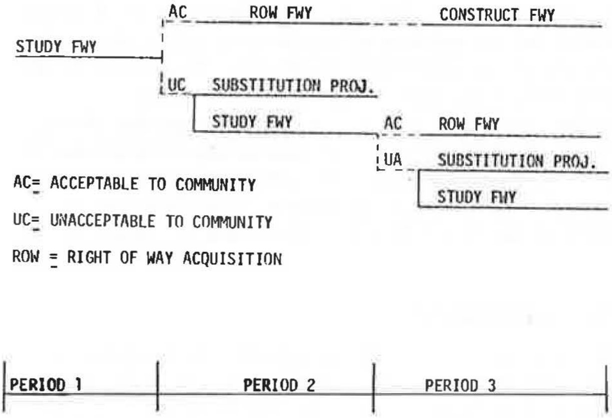
Figure 5. Expected value of designing freeway alternatives.



*AC - Acceptable to Community
UC - Unacceptable to Community
ROW - Right of Way Acquisition

Figures are expected net benefits in millions of dollars
discount rate = 5%

Figure 6. Staging strategy relating Santa Barbara corridor decision to planning program.



By evaluating the strategies considered in the previous project level example (but with the requirement now that a substitution program be funded if a design is unacceptable in a given period), the strategy with the highest expected net present value has changed from designing the at-grade alternative initially to designing the more costly depressed freeway. In fact, the strategy of designing the depressed freeway in the first period continued to have the highest expected net present value even when the probability of acceptance on the other alternatives increased to 50 percent. The implication is that the higher probability that the community will not accept the at-grade or elevated design, coupled with the need to fund premature and low benefit-producing substitution projects if the freeway is delayed, suggests that designing the depressed alternative in the first period may be a better decision with respect to increasing the expected economic efficiency from the entire planning program.

CONCLUSIONS

A broad application of the time-staging approach will allow system plans to both reflect and leave open a range of the choices available and at the same time restore more continuity to investment schedules.

When significant uncertainty exists, whether it involves community acceptance, demand forecasts, or another factor, a transportation agency should systematically examine the consequences of the uncertainty. One cannot eliminate the depressed alternative in the Santa Barbara case because of the $10 million cost differential without examining its probability of acceptance (or earlier acceptance) relative to other alternatives under consideration.

Even where significant uncertainties do not exist, the timing and design of projects in an investment program must be interrelated because of budget constraint. Transportation projects cannot be designed independently, but rather the design and timing of an improvement must reflect the alternative uses of those funds.

The role of system planning in the context of staged alternatives is to carefully anticipate the choice issues that must be resolved as planning continues and to devise tentative sequences of improvements based on potential outcomes from these choices. At the same time, it must be recognized that no amount of caution or effort can anticipate all the choice issues or recognize all the feasible alternatives. New options will be added at some later point and others will be dropped from consideration.

The time-staging approach is decisive, by requiring action on first-period plans, and realistic, by recognizing that it is neither desirable nor necessary to make tentative decisions over a long time horizon. While leaving future decisions open until more information is obtained, staging strategies take into account possible future options and events and are able to evaluate the most flexible direction for present decisions.

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